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LANDSCAPE BIODIVERSITY IN TERMS OF CROP STRUCTURES: A SPATIAL ASSESSMENT FOR POLAND

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One of determinants of the biodiversity of a landscape is the structure of farm crops. The agricultural practice of sowing a wide variety of crops each of which is well represented in the overall composition of crops has a positive impact on the diversity and abundances of fauna and flora species in a given area. The aim of the study is to identify and characterise spatial diversity in the compositional balance between different crops in Poland. The study employed one of the most popular biodiversity indices, the Shannon–Wiener index (H'), and the basic data was that of sown area (for 20 crops or crop groups) in 2020. The spatial scope of the work was Poland, divided into poviats (380 LAU-1 units). Generalising the results, a north–south divide is visible (with some exceptions, such as Żóławy Wiślane and Suwałki). Northern and central Poland have more balanced crop compositions, while the south sees far greater disproportions between individual crops. Crop structure was most balanced in poviats close to major cities (including Warsaw and Poznań), and least (discounting for urban poviats) in Żóławy Wiślane (around Malbork and Nowy Dwór Gdański). The structural diversity can be accounted for in terms of factors such as: natural predispositions for agricultural production (primarily, soil quality), distance from large cities (market) and organisational characteristics of the farms themselves (including, above all, the spatial distribution of farms of various sizes, which in Poland is the result of historical political divisions).

Keywords: *cropping structure; agriculture; socio-economic geography; Shannon–Wiener index; diversity; poviat.*

INTRODUCTION

The configuration of a landscape and the processes taking place in it are inextricably linked to biodiversity. Biodiversity is at its maximum where landscape configurations and processes are most heterogeneous (Bridgewater, 1988). Particular attention should be paid to agricultural land, which comprises the largest human-managed ecosystem in the world. Increasing agricultural landscape complexity has a positive impact on biodiversity (Batary et al., 2020; Estrada-Carmona et al., 2022; Moss et al., 2020). Measuring the complexity of agricultural landscapes is extremely complicated (Leser & Nagel, 2001; Walz, 2011), although three main dimensions influencing ecological processes are emphasised. These are composition, configuration and heterogeneity. The composition of the landscape relates to how much land is devoted to each habitat or land-use type (e.g., wooded areas, farmlands), each of which has its own typical species profile. Landscape configuration relates to the size, shape and layout of these habitat types, which through, for example, the length of natural boundaries, determines the opportunities for mobility and interactions between species. The last dimension of landscape complexity – heterogeneity – is determined by the number of crops. High heterogeneity is associated with better provision of resources throughout the year in dynamic landscapes (Estrada-Carmona et al., 2022).

Thus, one of the factors affecting landscape biodiversity is the structure of farm crops (Kęsik, 2008; Matyka, 2017; Pajewski, 2017; Madej 2023). A diverse, uniform crop structure (many different crops covering similarly sized areas) has a positive effect on the diversity and abundance of fauna and flora species in an area. By contrast, a simplified crop structure involves an area being sown with only a few species (often over a period of several years) or, in extreme cases, only one crop (monoculture). In the European Union (EU), the Common Agricultural Policy (CAP) offers a number of measures (e.g., greening, agri-environmental measures, organic farming) and financial incentives designed, among other things, to encourage optimal landscape structure. Therefore, in (but not limited to) monitoring the effectiveness of EU environmental policies, it is important to quantitatively assess biodiversity at various spatial and temporal scales. Comprehensive spatial studies that take into account administrative divisions can be particularly valuable (e.g., Matyka, 2018; Neogi & Bidyut, 2022). In such cases, it is necessary to use mass statistics, which are usually collected by selected public institutions. In Poland, these are Statistics Poland (CSO, *Central Statistical Office*) and the Agency for Restructuring and Modernisation of Agriculture, which administrates EU CAP funds. This involves certain limitations on material scope (detail specifying certain crops individually), temporal scope (data for individual years, seasons, etc.) or spatial scope (there is usually more information for larger administrative units). Agricultural censuses provide special opportunities in this respect, as they comprehensively document the state of farms throughout the country at a given moment.

The aim of the study is to identify and characterise the spatial differentiation in compositional balance of crops at the poviat level in Poland. Research on agricultural geography usually analyses the distribution of individual crops, while sometimes attempting to adopt a synthetic approach in the form of a typology (Rudnicki, 2016).

RESEARCH METHODS

The study was based on data from the General Agricultural Census 2020 in Statistics Poland's (CSO) Local Data regarding the area of individual crops as of June 31, 2020. After verification of the available data, the following crops and crop groups were included for further analysis: winter wheat (including spelt) (1), spring wheat (including spelt) (2), winter rye (3), spring rye (4), winter barley (5), spring barley (6), oats (7), winter triticale (8), spring triticale (9), winter cereal mixtures (10), spring cereal mixtures (11), maize for grain (12), industrial (annuals) (13), total edible legumes for dry grain (14), potatoes (15), sugar beets (16), oilseed rape and agrimony, combined (17), field vegetables (18), spring catch crops (19), winter catch crops (20). In addition to data on individual species (e.g., wheat, rye, etc.), the data used contains information aggregated into entire groups of crops (e.g., field vegetables, industrial crops). The data were aggregated by the location of each farm's headquarters.

Diversity of crop composition was assessed using one of the most popular biodiversity indicators (Feledyn-Szewczyk, 2013; Matyka, 2017; Neogi & Bidyut, 2022; Njeru et al., 2022) – the Shannon–Wiener index (H') (Shannon & Wiener, 1949), as determined by the formula:

$$H' = -\sum_{i=1}^{S}(p_i)(\ln p_i), \tag{1}$$

where H' – Shannon–Wiener index;
p_i– area per crop, ha;
ln– natural logarithm

Calculated in this way, the highest index values indicate an even share of species (i.e., the species have the same p_i factor as each other). Assuming poviats with identical numbers of crops, the biodiversity index will be higher in the poviat with the more even distribution of crops.

The spatial scope of the study was the whole of Poland broken down into poviats. A poviat is a unit of local government (the second-order subdivision) classified in the European Union as an LAU-1 region. Currently, there are 380 poviats in Poland, comprising 314 land poviats and 66 cities with poviat rights. The research results were presented using pie charts and simple choropleth maps. Additionally, there are maps showing the land use of selected areas (CORINE Land Cover, Google maps). It should be emphasised that the adopted methodology allows the complexity of crop structure to be assessed by the number and area of crops. This is one of several dimensions that should be taken into account in studies of the complexity – and thus biodiversity – of landscape.

RESULTS AND DISCUSSION

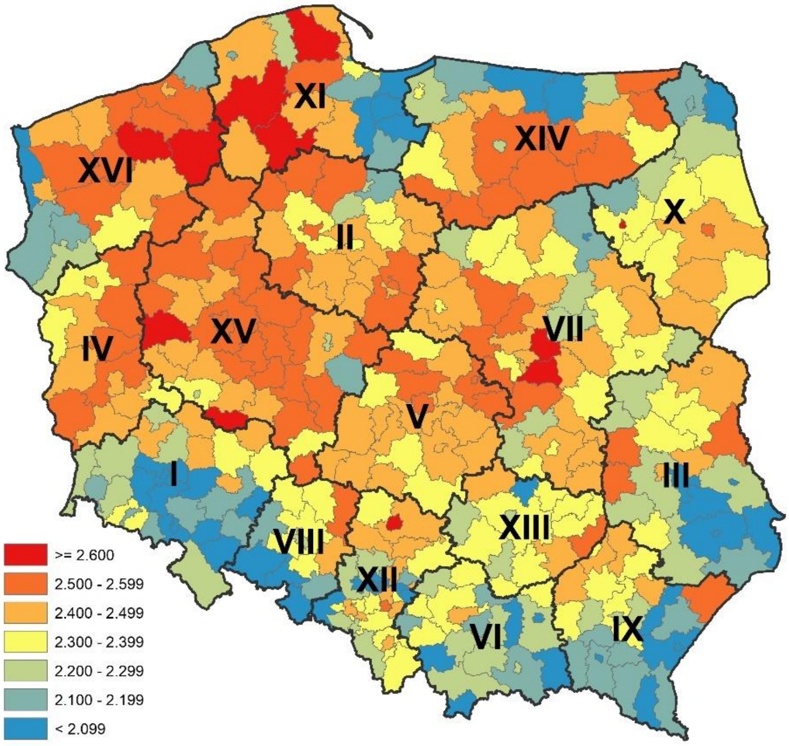
Agricultural land constitutes 58% of Poland by area. In 2020, it comprised almost 11 million ha of the country, and over the previous decade this area had increased by 5.7% (CSO, 2022).The country's location in a temperate climate zone and its diverse soil cover allow plant production that is diversified between more- and less-demanding species (Bański, 2007). Arable land, being subject to long-term mechanical cultivation, including sowing, is of particular importance for biodiversity.

The diversified crop production potential is confirmed by the analysis of the number of crops per poviat (maximum 20). In as many as 238 poviats (62% of the total) this number exceeded the average value (18.1), while the maximum number was recorded in 148 (39%). Only in three poviats did the number of crops not exceed ten (including touristic Tatrzański poviat in Lesser Poland Voivodship).

The average Shannon–Wiener index value was 2.36 points. The index value varied spatially and ranged from below 2.00 points in 31 poviats (most often in: Silesia Voivodeship, 6 poviats; Lower Silesia, 5; and Lesser Poland, 4) to over 2.60 points in 11 poviats (most often in Pomerania Voivodeship, 3 poviats; Masovia Voivodeship, 2; Greater Poland Voivodeship, 2; and West Pomeranian Voivodeship, 2) (see Fig. 1).

It should be noted that, excluding the cities with poviat rights (Siemianowice Śląskie, Gliwice, Przemyśl, Legnica, Jaworzno, Chorzów, Zabrze, Ostrołęka, Ruda Śląska, Zamość, Tarnów), where agriculture often plays a minor role (e.g., in the city of Chorzów, farms occupied only 211 ha), the poviats with the lowest levels of biodiversity included units with very good natural conditions for agricultural production and a well-developed agricultural sector. These included the Malbork poviat (1.77 points), Nowy Dwór poviat (1.84 points) and Sztum poviat (1.94 points), all of which are in Pomerania Voivodeship. These are areas located largely within Żóławy Wiślane, which is a specific physical geographical unit covering the vast Vistula delta plain. They are flat areas, more than 90% composed of fertile alluvia (Nowicki & Liziński 2004) and considered among the best in the country for agricultural production (Rudnicki, 2016). The above, combined with the organisational conditions of the farms (former state-owned farms, characterised by large average farm size and large average agricultural plot size (Rudnicki, 2016), determined the high level of specialisation in plant production. For example, in the Malbork poviat, just two crops (winter wheat and oilseed rape) accounted for over 72%

of total sown area. It should be noted that such high percentages of over one third of total composition are predominantly seen for winter wheat, but there are also a few poviats in which rye, triticale, cereal mixtures, maize corn and oilseed rape occupy such positions. Moreover, in the case of three cities (Sopot, Świętochławice, Świnoujście), data show that no farms sowed any crops.



Source: own study based on BDL GUS.
Voivodeships are indicated with Roman numerals: I – Lower Silesia (LS), II – Kuyavia-Pomerania (KP), III – Lublin (LI), IV – Lubusz (LU), V – Łódź (LD), VI – Lesser Poland (LP), VII – Masovia (MS), VIII – Opole (OP), IX – Subcarpathia (SC), X – Podlasie (PL), XI – Pomerania (PM), XII – Silesia (SL), XIII – Holy Cross (HC), XIV – Warmia-Masuria (WM)), XV – Greater Poland (GP), XVI – West Pomerania (WP).

Figure 1. Shannon–Wiener Index (2020).

The units with the greatest crop heterogeneity were concentrated in the central and northern parts of the country (see Fig. 1). Heterogeneity was highest in the poviats of Piaseczno (2.67 points; Masovia Voivodeship), Wejherowo (2.66 points; Pomerania Voivodeship) and Nowy Tymski (2.64 points; Greater Poland Voivodeship). All three of these poviats have a common feature, namely they are close to major cities (respectively, Warsaw, the Gdańsk–Gdynia–Sopot Tricity and Poznań). The shares of individual crops or crop groups are much more uniform. Thus, the Piaseczno district was characterised by above-average shares of field vegetables (at 12.2% compared to the average for Poland of 1.5%), potatoes (5.9%, national average 2.0%) and legumes (3.0%, national average 1.0%). In turn, the average share of winter wheat in the three mentioned counties was much lower than the national level (13.2% compared to the average of 20.8%).

(a) Piaseczno poviat; (b) Malbork poviat.
Source: own study based on BDL GUS.

Figure 1. Example charts presenting sowing structure

This confirms previous research findings that urban centres have a strong impact on the structure of agricultural land and the intensity of agriculture (Sroka, 2014). A greater market for local consumption usually causes an increase in the area dedicated to vegetables, cultivation under cover (tunnels, greenhouses, etc.), orchards and potato cultivation (Falkowski & Kostrowicki, 2001). On the other hand, more intensive production means more mineral fertilisation and greater use of chemical plant protection products.

Generalising the results, there is a clear north–south divide (with some exceptions, such as Żóławy Wiślane or Suwałki). Northern and central Poland have more balanced crop compositions, while the south sees far greater disproportions between individual crops. This confirms the author's previous research results on regional changes in the structure of crops during the period of EU membership (Wiśniewski, 2023). The values of the H' index in 2004–21 decreased most in the north-east and south of the country, especially in Lesser Poland Voivodeship. This region's agricultural areas are fragmented and overpopulated (average farm area in 2022, 4.28 ha, with a national average of 11.32 ha) and the voivodeship has a high concentration of Poland's agricultural "problem areas" (Bański, 1999). Crop structure is being simplified as part of the process of deagrarianisation, which means that agriculture in Lesser Poland is fulfilling its economic, social and, above all, environmental functions ever less (Sroka 2018). The improvement in the balance of crop structure was greatest in Łódź Voivodeship (Wiśniewski, 2023). The pie charts (see Fig. 2) present an overview of crop structures in Malbork and Piaseczno poviats, while Figures 3 and 4 contain maps showing selected places from the analysed case studies (Piasekno and Malbork poviats) at various spatial scales. Figure 3 (Google maps) shows contrasting areas in terms of local-scale landscape complexity, while Figure 4 (Corine Land Cover) well illustrates the differences in complexity at a regional scale.

a

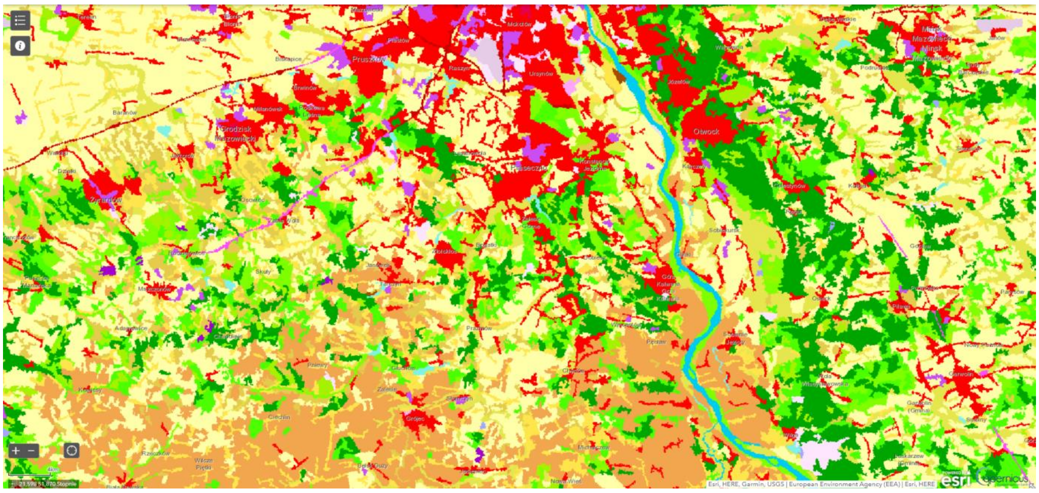
B

(a) Tarczyn and surroundings (Piaseczno poviat) – example of an area with a heterogeneous crop structure; (b) Tragamin and surroundings (Malbork poviat) – example of an area with a more homogeneous crop structure
Source: Google maps (accessed: September 1, 2023)

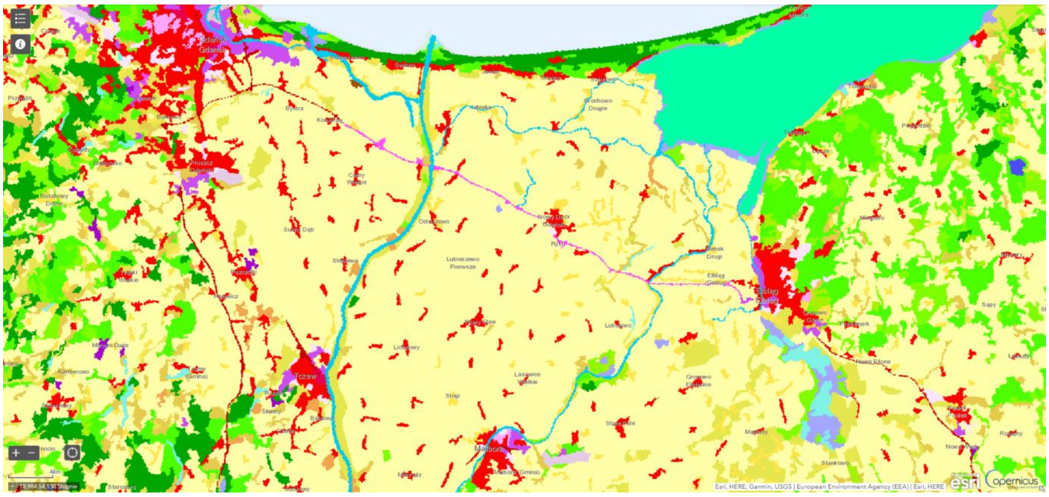
Figure 3. Sample fragments of rural maps showing crop diversity (same scale)

Merlos and Hijmans (2022) examined the gap between achievable and current crop diversity at a global scale and found that it is particularly large in most of the Americas and relatively small in some parts of Europe and East Asia. In Poland, they found the gap to be largest in the south-east, which confirms the main findings of the present study. Moreover, they found that the main reason for low levels of local crop diversity around the world is specialisation by farms and regions, rather than the world's dependence on a few key crops. This confirms the general conclusions of the present study indicating the role of non-natural determinants of crop structures.

However, there is evidence pointing to the importance of natural factors (Donfouet et al., 2017; Neogi & Ghosh, 2022), especially access to water (LaFevor & Pitts, 2022). Research in Mexico shows that irrigation levels (% of cropland irrigated) are a strong positive predictor of crop species richness and evenness of diversity across regions (LaFevor & Pitts, 2022). However, this is not a global rule, because in some regions (especially in Asia: e.g., China, Bangladesh) irrigation leads to less diversity of crops (greater specialisation), because farmers use water to increase productivity (yields) while focusing on a few monoculture crops that require large amounts of water and produce high yields (Headey & Hoddinott, 2016). The same applies to Żóławy Wiślane (Poland), an area which, despite having a well-developed drainage network, is essentially monocultural (with a dominance of wheat and rapeseed). Neogi and Ghosh (2022) showed that, in India, in addition to irrigation intensity, crop diversification was also influenced by other such factors as rural literacy, road infrastructure, *per capita* population, gross domestic product and access to credit.



A



b

(**a**) Piaseczno area (south of Warsaw) – example of complex and heterogeneous landscape; (**b**) Żóławy Wiślane (east of Gdańsk) – example of homogeneous landscape
Source: CORINE Land Cover (accessed: September 9, 2023)

Figure 4. Sample fragment of CORINE Land Cover maps (same scale)

By closing the gap between current and potential diversity, crop diversity could double on 84% of the world's agricultural land without changing the total amount of food produced globally (Merlos & Hijmans, 2022), and this would improve the quality and value of ecosystem services provided (Sujetovienė & Dabašinskas, 2023). The *Common Agricultural Policy* and the *European Green Deal* strategy play an important role in this respect, improving the biodiversity of the agricultural landscape through various financial incentives (Vistarte et al., 2023). In addition to its environmental benefits, crop diversification brings positive economic and social effects such as increased exports and new jobs (Neogi & Ghosh, 2022). This is also true of Poland (Feledyn-Szewczyk, 2016).

CONCLUSIONS

Differences between poviats in terms of the spatial homogeneity of their crop structures were identified, and thus the contribution of agriculture to building one of the important elements shaping landscape biodiversity. The existence of a diverse and balanced composition of crops (which cover almost 11 million ha – one third of the country's total area) has a positive impact on the richness of fauna and flora of local ecosystems, in contrast to a simplified structure dominated by one or several crop species.

The study aimed to identify spatial differences in the homogeneity of crop composition at the poviat (LAU-1) level. Poland is spatially diverse, with a general division into northern-central and southern parts. The structural diversity should be accounted for in terms of factors such as: natural predispositions for agricultural production (primarily, soil quality), distance from large cities (market) and organisational characteristics of the farms themselves (including, above all, geographical differences in average farm size, which in Poland is the result of historical political divisions)(Rudnicki et al., 2017). The findings should be taken into account in shaping territorially targeted support under CAP programmes and activities aimed at protecting biodiversity.

The author emphasises the importance of studies adopting an appropriate spatial resolution, as this will determine whether the spatial diversity of the studied phenomena will be appropriately identified. Further analyses are needed that will take into a far greater number of crops (using the registers of the Agency for Restructuring and Modernisation of Agriculture – the entity disbursing CAP funds in Poland). These studies will need to be carried out for smaller spatial units (municipalities, geodetic districts) and for various periods of time (to identify the directions and paces of changes) and using a range of research methods and approaches.

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